

## 1 HYBRID ROCKET MOTOR HAVING A PRECOMBUSTION CHAMBER

## 3 BACKGROUND OF THE INVENTION

## 5 1. Field of the Invention

6 This invention relates broadly to self-propelled projectiles.  
7 More particularly, this invention relates to rockets powered by  
8 hybrid propellant systems.

## 10 2. State of the Art

11 Rocket boosters (motors) generally fall into three classes:  
12 solid propellant boosters in which a solid fuel element, or grain,  
13 undergoes combustion to produce thrust that propels the rocket,  
14 liquid propellant boosters that accomplish the same function with  
15 a liquid fuel material, and hybrid boosters, described below.  
16 Solid and liquid rocket boosters can produce relatively large  
17 amounts of thrust, but for a relatively short amount of time. In  
18 addition, solid and liquid rocket boosters are generally expensive  
19 to develop and produce due to the inherent dangers of the highly  
20 combustible solid fuels and the complexity of bipropellant liquid  
21 feed systems.

23 Hybrid rocket boosters are described in detail in co-owned  
24 U.S. Patent No. 5,715,675 to Smith et al., which is hereby  
25 incorporated by reference herein in its entirety. They have been

1 characterized as a cross between a solid propellant booster and a  
2 liquid propellant booster. Generally, hybrid boosters use a fluid  
3 reactant (an oxidizer) to burn a solid fuel element, although they  
4 may use a combustible liquid fuel and a solid reactant. The solid  
5 element is generally formed as a thick-walled tubular cylinder,  
6 defining a port of a combustion chamber along its length. The  
7 hybrid rocket propellant (fuel and reactant together) can be  
8 ignited by a pyrotechnic igniter, such as an  
9 electrically-generated spark. The fuel of a hybrid rocket is  
10 inert until mixed with the oxidizer in the presence of an igniter  
11 in the combustion chamber. As such, there is no danger of  
12 inadvertent and uncontrollable combustion.

13  
14 Hybrid rockets are subject to an oscillation in thrust level  
15 during burn of the propellant called "combustion instability".  
16 Combustion instability can vary from severe, oscillating between  
17 zero and one hundred percent thrust, to a currently acceptable  
18 standard of less than ten percent, and more preferably less than  
19 five percent. The inventors hypothesize that the instability is  
20 caused by the flame front drifting back and forth along the length  
21 of the fuel grain. The drift may be caused by injected oxidizer  
22 actually 'blowing out' the flame. The result of flame front drift  
23 is a change in the oxidizer/fuel ratio and combustion efficiency,  
24 as well as corresponding thrust levels. The instability is most  
25 evident in high mass flux ratio (Gt) motors, with the mass flux

1 ratio calculated as propellant lbs•sec/area of the port measured  
2 in square inches. In a typical well-designed hybrid motor, an  
3 unacceptable level of combustion instability occurs with a mass  
4 flux ratio of 0.5 or more. However, a higher mass flux ratio is  
5 desired, as increasing the mass flux ratio permits the diameter of  
6 the port within the solid fuel to be reduced and the web thickness  
7 (thickness of the solid fuel wall) to be increased, thereby  
8 significantly increasing the volumetric loading of a motor, as  
9 well as burn time and total impulse.

#### 11 SUMMARY OF THE INVENTION

13 It is therefore an object of the invention to provide a  
14 hybrid rocket motor which burns with high stability.

16 It is also an object of the invention to provide a hybrid  
17 rocket motor having a higher mass flux ratio.

19 It is another object of the invention to provide a hybrid  
20 rocket motor which increases volumetric loading, burn time, and  
21 total impulse.

23 In accord with these objects, which will be discussed in  
24 detail below, a rocket is provided which includes a hybrid motor,  
25 a casing about the hybrid motor, an aft nose cone, and a rear

1 nozzle. The hybrid motor includes a storage tank which stores  
2 fluid reactant (oxidizer), a combustion chamber, a solid fuel  
3 grain defining a central port within the combustion chamber, and  
4 an injector adapted to inject the oxidizer into the combustion  
5 chamber. According to the invention, a flame holder is provided  
6 at a head end of the combustion chamber and maintains a flame  
7 adjacent the injector. The flame holder stabilizes the flame  
8 front and prevents the flame front from drifting along the fuel  
9 grain, which the inventors believe to be a cause of combustion  
10 instability, thereby reducing or eliminating combustion  
11 instability.

12  
13 According to one embodiment, the flame holder includes a  
14 high-temperature casing defining a cavity at the head of the  
15 combustion chamber, and a solid propellant within the cavity  
16 around or near the injector. The propellant may be generally  
17 cylindrical within a cylindrical casing, such that the flame plume  
18 of the burning propellant is substantially perpendicular to the  
19 oxidizer flow, or may be provided in an annulus within the casing,  
20 such that the flame plume from the burning propellant is  
21 substantially parallel to the flow of the oxidizer. The solid  
22 propellant is preferably ignited substantially simultaneously with  
23 the ignition of the hybrid motor. The burning of the solid  
24 propellant prevents the flame which results from combustion of the

1 fluid oxidizer and solid fuel in the hybrid motor from drifting,  
2 and thereby stabilizes the flame front for the hybrid motor.

3  
4 According to another embodiment, the flame holder is a pre-  
5 combustion chamber supplied with propellant from separate fuel and  
6 oxidizer sources. The propellant can be in the form of gas or  
7 liquid and injected substantially tangentially into the head end  
8 of the hybrid motor adjacent the oxidizer injector to form a  
9 propellant swirl. As the hybrid motor oxidizer is injected into  
10 the swirl, it is heated and gasified, and assumes a swirling  
11 motion which increases the oxidizer path length and thereby  
12 increases the dwell time of the oxidizer. The increased dwell  
13 time increases combustion efficiency. The precombustion chamber  
14 can be held in an "idle" state (i.e., when no hybrid motor  
15 oxidizer is injected through the injector), allowing the hybrid  
16 motor to have multiple restarts without multiple pyrotechnic  
17 igniters. Additionally, the precombustion chamber fuel and  
18 oxidizer may be adjusted during hybrid motor burn as needed based  
19 on hybrid motor oxidizer flow rates.

20  
21 According to a further embodiment of the invention, the  
22 injector is extended into the combustion chamber to form a  
23 toroidal precombustion chamber therebehind which has a controlled  
24 exit area (annular nozzle) adjacent a face of the injector. Solid  
25 fuel may be provided in the chamber or liquid fuel may be injected

1   therein. In either case, oxidizer is injected into the  
2   precombustion chamber, either from a separate source or from a tap  
3   on the main oxidizer line. The oxidizer and fuel mix and travel  
4   in a swirling motion and generate heat sufficient to function as a  
5   flame holder. The heated flow is ejected from the exit area into  
6   the combustion chamber. The precombustion chamber heat generation  
7   may be controlled or interrupted by control of the flow of  
8   oxidizer into the precombustion chamber.

9  
10       The additional heat and energy added to the head end of the  
11   combustion chamber vaporizes the oxidizer as it is injected into  
12   the combustion chamber, thereby maximizing surface area of the  
13   oxidizer, and reducing reaction time of the fuel-oxidizer  
14   propellants. This operates to ensure that a flame head does not  
15   drift and is stabilized at the injector.

16  
17       Additional objects and advantages of the invention will  
18   become apparent to those skilled in the art upon reference to the  
19   detailed description taken in conjunction with the provided  
20   figures.

## BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a broken schematic longitudinal section view of a rocket provided with a hybrid motor and a flame holder according to a first embodiment of the invention;

Fig. 2 is a relatively enlarged broken schematic section view of the flame holder according to the first embodiment of the invention;

Fig. 3 is a broken schematic section view of a flame holder in a rocket body according to a second embodiment of the invention;

Fig. 4 is a broken schematic longitudinal section view of a rocket provided with a hybrid motor and a precombustion chamber flame holder according to a third embodiment of the invention;

Fig. 5 is a broken schematic section view of the precombustion chamber flame holder according to the third embodiment of the invention;

Fig. 6 is a cross-section across line 6-6 in Fig. 5;

1        Fig. 7 is a broken schematic longitudinal section view of a  
2 precombustion chamber flame holder in a rocket body according to a  
3 fourth embodiment of the invention;

4  
5        Fig. 8 is a relatively enlarged broken schematic section view  
6 of the pre-combustion chamber flame holder according to the fourth  
7 embodiment of the invention;

8  
9        Fig. 9 is a cross-section across line 9-9 in Fig. 8; and

10  
11       Fig. 10 is a broken schematic section view of a precombustion  
12 chamber flame holder according to a fifth embodiment of the  
13 invention.

14  
15                    DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

16  
17        Turning now to Figs. 1 and 2, a rocket 10 includes a hybrid  
18 motor 12 surrounded by a tubular body 14, a nose cone 16 at a  
19 front end of the body, and an exhaust nozzle 18 at an aft end of  
20 the body. The hybrid motor 12 includes a storage tank 20 holding  
21 a pressurized fluid oxidizer 22, preferably liquid oxygen, and a  
22 combustion chamber 24 having a solid fuel 26, such as hydroxyl-  
23 terminated polybutadiene (HTPB). The solid fuel 26 defines a  
24 central port 28 through the combustion chamber 24. The oxidizer  
25 is fed from the tank 20 through a valved outlet 29 to an injector



1 30. A face 32 of the injector includes a plurality of holes 34  
2 through which the oxidizer 22 is injected into the combustion  
3 chamber 24. The oxidizer 22 may be pressurized to the high  
4 pressure required for injection by using a pressurant, e.g.,  
5 helium or nitrogen, in the tank 20, or by using a pump (not shown)  
6 between the tank 20 and the injector 30.

7  
8 According to the invention, a flame holder 36 is provided and  
9 maintains a flame adjacent the injector 30. One type of flame  
10 holder 36 according to the invention includes a casing 38 defining  
11 a cavity 40 at the head end of the combustion chamber 24,  
12 extending around or adjacent the injector 30. The casing 38 may  
13 be comprised of an injector ring 38a, and a precombustion ring  
14 38b, or formed as a unitary construct. The casing 38 is made from  
15 a material than can withstand high temperatures and pressures  
16 relative to the rocket body 14 material. One preferred material  
17 is glass-filled phenolic resin. A solid rocket propellant 42 is  
18 provided within the cavity 40 around or adjacent the injector.  
19 The propellant 42 is preferably a high metal content propellant  
20 such as AP/HTPB (ammonium perchlorate/hydroxyl-terminated  
21 polybutadiene), but may be any other solid propellant known in the  
22 art, including, but not limited to, double base, GAP, gas  
23 generator fuels, and black powder.

24

1        According to a first embodiment of the invention, the cavity  
2 40 and propellant 42 are each generally tubular in shape. The  
3 solid propellant 42 is preferably ignited, e.g., with a  
4 pyrotechnic igniter 44, substantially simultaneously with the  
5 ignition of the hybrid motor 12. As the web thickness of the  
6 solid propellant (the thickness of the propellant in the direction  
7 of its burn) is generally perpendicular to a longitudinal axis  $A_L$   
8 of the combustion chamber, the burning propellant 42 creates a  
9 flame plume generally in the direction of arrows  $P_1$ ; i.e.,  
10 substantially perpendicular to the flow of oxidizer from the  
11 injector 30. The flame plume functions as a 'pilot light' and  
12 stabilizes the flame front at the head end of the combustion  
13 chamber and prevents the flame front from drifting along the fuel  
14 grain. The flame holder reduces or eliminates combustion  
15 instability caused by flame drift.

16  
17        The flame holder has a burn time limited by the web  
18 thickness. The size of the web thickness in the 'core burning'  
19 configuration of the first embodiment is limited by the diameter  
20 of the combustion chamber, and generally smaller than the web  
21 thickness of the solid fuel grain. Given the relatively limited  
22 time over which the flame holder can function, the flame holder of  
23 Figs. 1 and 2 is ideal for short burn, high thrust, liquid oxygen  
24 hybrid motors.

1 Referring to Fig. 3, a hybrid rocket 110 having a second  
2 embodiment of a flame holder 136 is shown. The flame holder 136  
3 includes a casing 138 about the injector which defines an annular  
4 cavity 140 which is provided with solid propellant 142. The  
5 propellant 142 has a web thickness measured substantially parallel  
6 to longitudinal axis  $A_L$  of the combustion chamber such that it is  
7 'end burning' with the flame plume extending substantially  
8 parallel to the flow of the oxidizer; i.e., in the direction of  
9 arrows  $P_2$ . In the second embodiment, by adjusting the depth of the  
10 cavity, the web thickness of the solid propellant can be adjusted  
11 to correspond to the burn time of a given hybrid system. In fact,  
12 unlike the first embodiment, the web thickness of the solid  
13 propellant can be greater than the web thickness of the solid fuel  
14 grain. As such, the second embodiment of the flame holder 136 is  
15 suitable for both short and long burn hybrid motors.

16  
17 Turning now to Figs. 4, 5 and 6, according to a third  
18 embodiment of the invention, a hybrid rocket motor 212 is provided  
19 with a precombustion chamber 250. The precombustion chamber 250  
20 is defined by a casing 238 made from a high temperature, high  
21 pressure material, such as glass-filled phenolic resin, and  
22 provided at the head end of the combustion chamber 224. The  
23 precombustion chamber 250 is spaced between the oxidizer injector  
24 230 and the solid fuel grain 226. The oxidizer injector 230

1 extends into the precombustion chamber 250 such that a toroidal  
2 space 251 is defined rearward of the injector face 232.

3  
4 Coupled to the precombustion chamber 250 are pathways 252,  
5 254 which terminate at injectors 256, 258 that are oriented to  
6 substantially tangentially direct a gas or fluid into the toroidal  
7 space 251 of the precombustion chamber 224. A pressurized fuel  
8 tank 260 is coupled to one of the pathways 252, and a pressurized  
9 oxidizer tank 262 is coupled to the other of the pathways 254.  
10 Each tank 260, 262 is provided with a valve 264, 266 which  
11 controls the flow and flow rate of fuel and oxidizer from the  
12 tanks 260, 262, into the pathways 252, 254, through the injectors  
13 256, 258 and into the chamber 250. Alternatively, rather than  
14 using a separate oxidizer tank 262, the oxidizer may be tapped off  
15 from the main oxidizer tank 222. This option is discussed below  
16 with respect to another embodiment. When the fuel and oxidizer  
17 enter the precombustion chamber, they form a propellant swirl  
18 travelling in a vortex, as indicated by arrows S, which is  
19 combusted to generate heat adjacent the oxidizer injector 230.  
20 The fuel and oxidizer may be a self-igniting mixture using:  
21 oxidizers such as gaseous or liquid oxygen; pyrophoric materials  
22 such as triethyl aluminum, trimethyl aluminum, or triethyl  
23 borine; and fuels such as propane, ethane or ethylene.  
24 Alternatively, the fuel/oxidizer mixture may be hypergolic (self-  
25 igniting oxidizer and fuel), e.g., nitric acid and aniline. The

1 amount of heat can be adjusted by adjusting the flow rates of the  
2 fuel and oxidizer into the precombustion chamber.

3  
4 As the hybrid motor oxidizer from tank 222 is injected into  
5 the swirl by the oxidizer injector 230, it is heated and gasified,  
6 and assumes a swirling motion which increases the hybrid motor  
7 oxidizer path length and thereby increases the dwell time of the  
8 hybrid motor oxidizer. The increased dwell time increases  
9 combustion efficiency. The precombustion chamber can be held in  
10 an "idle" state (i.e., when no hybrid motor oxidizer is injected  
11 through the injector), allowing the hybrid motor to have multiple  
12 restarts without multiple pyrotechnic igniters. Additionally, the  
13 precombustion chamber fuel and oxidizer may be adjusted during  
14 hybrid motor burn as needed based on hybrid motor oxidizer flow  
15 rates. Moreover, the precombustion chamber 250, including the  
16 toroidal space 251, defines a recirculation zone in which the flow  
17 of heat generated by combustion is recirculated, as indicated by  
18 arrows R, to facilitate holding a flame at the head end of the  
19 main combustion chamber 224.

20  
21 Turning now to Figs. 7, 8 and 9, according to a fourth  
22 embodiment of the invention, the main oxidizer injector 330 is  
23 extended toward the combustion chamber 324, and a casing 338 is  
24 provided against the wall of the rocket body 314 and about the  
25 main injector 330 to define a toroidal precombustion chamber 350

1 about the extension 331 of the main injector. The precombustion  
2 chamber 350 has a controlled exit area (annular nozzle) 351 near  
3 the face 332 of the injector 330. According to the fourth  
4 embodiment, liquid fuel, but not necessarily oxidizer, is injected  
5 into the precombustion chamber via pathways 352 and 354 and  
6 through two injectors 356, 358 in a manner substantially as  
7 described in the third embodiment; i.e., plumbed from a tank  
8 source (not shown) into the tangential injectors 356, 358. The  
9 oxidizer may also be supplied from a separate tank and plumbed  
10 into the precombustion chamber as also described in the third  
11 embodiment. Alternatively, as shown in Fig. 8, the oxidizer may  
12 be tapped, or may be rom the main oxidizer tank 222 (Fig. 4) and  
13 passed through injector holes 360 in the main injector 330 into  
14 the precombustion chamber 350. The fuel and oxidizer mix in the  
15 precombustion chamber 350 and travel in a swirling motion imparted  
16 by the tangential injection of the fuel (and possibly oxidizer)  
17 and are combusted. The heated flow of combustion products is  
18 ejected from the nozzled exit area 351 into the combustion chamber  
19 324, and functions as a small rocket motor integrally surrounding  
20 the main injector 330. The precombustion chamber heat generation  
21 may be controlled or interrupted by control of the flow of fuel or  
22 oxidizer into the precombustion chamber. The additional heat and  
23 energy added to the head end of the combustion chamber vaporizes  
24 the oxidizer as it is injected into the combustion chamber,  
25 thereby maximizing surface area of the oxidizer, and reduces

1 reaction time of the fuel-oxidizer propellants. This operates to  
2 ensure that a flame head does not drift and is stabilized at the  
3 injector.

4  
5 Turning now to Fig. 10, a fifth embodiment of a precombustion  
6 chamber 450, substantially similar to the fourth embodiment, is  
7 shown. The casing 438 defining the chamber 450 also defines a  
8 recess 470 which is at least partially filled with solid fuel 472.  
9 The oxidizer is supplied into the precombustion chamber through  
10 tap injectors 460, and combusted with the solid fuel to provide  
11 the same benefit as in the previous embodiment.

12  
13 By using a flame holder, as described in the several  
14 embodiments above, a mass flux ratio in excess 1.0 has been  
15 achieved. The increased mass flux ratio permits the use of a  
16 smaller diameter port (space within the solid fuel grain), thereby  
17 increasing the web thickness of the solid fuel. The result is a  
18 significant increase in volumetric loading of the hybrid motor,  
19 burn time, and total impulse.

20  
21 There have been described and illustrated herein several  
22 embodiments of a flame holder and a precombustion chamber for a  
23 hybrid rocket motor, and rocket provided with such hybrid motor.  
24 While particular embodiments of the invention have been described,  
25 it is not intended that the invention be limited thereto, as it is

1 intended that the invention be as broad in scope as the art will  
2 allow and that the specification be read likewise. Thus, while  
3 the preferred oxidizer is liquid oxygen, it will be appreciated  
4 that other non-self pressurizing oxidants such as red fuming  
5 nitric acid (RFNA), nitrogen tetroxide (NTO), and hydrogen  
6 peroxide ( $H_2O_2$ ), provided with a pressurant such as nitrogen or  
7 helium, may also be used, and that self-pressurizing oxidizers  
8 such as gaseous oxygen, fluorine, nitrous oxide ( $NO_2$ ), or carbon  
9 dioxide ( $CO_2$ ) can also be used. Furthermore, if  $H_2O_2$  is the  
10 oxidant, a fuel component is not required in the precombustion  
11 chamber. Rather, a catalyst can be used with the  $H_2O_2$ . The  
12 catalyst may be either a solid located in the precombustion  
13 chamber, e.g., samarium nitrate ( $Sm(NO_3)_3$ ) on silver or silver-  
14 plated nickel mesh, or a fluid injected into the precombustion  
15 chamber, e.g., a potassium permanganate solution injectant.  
16 Moreover, a fuel (either solid or liquid) may then additionally be  
17 provided to react with the catalyzed  $H_2O_2$ .

18  
19 Also, while the hybrid fuel grain is preferably HTPB, other  
20 fuel grains known in the art, such as ABS resin, CTPB, PBAN or  
21 other fuel/binder systems may be used.

22  
23 In addition, while the casing is shown to define particular  
24 cavity shapes, it will be appreciated that cavities having other  
25 shapes can be used. For example, with respect to the first



1 embodiment of the flame holder (Fig. 2), the casing may be a  
2 straight cylinder and define a cylindrical cavity provided with  
3 cylindrically configured solid rocket propellant. Also, while in  
4 the first and second embodiments web thicknesses have been shown  
5 in two exemplar directions, it will be appreciated that the web  
6 thickness may be in a direction which is oblique relative to the  
7 axis of the combustion chamber. Furthermore, in each of the first  
8 and second embodiments, the solid fuel is spaced from the solid  
9 propellant such that they are not in contact. This is not a  
10 requirement of the invention. Moreover, with respect to the pre-  
11 combustion chambers, each may be fed oxidizer from the main  
12 oxidizer tank or from a separate tank. It will therefore be  
13 appreciated by those skilled in the art that yet other  
14 modifications could be made to the provided invention without  
15 deviating from its spirit and scope as so claimed.